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INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is September 17, 2013. This oral history interview with Frank Hughes is being conducted in Houston, Texas, for the NASA Johnson Space Center Oral History Project. Interviewer is Rebecca Wright, assisted by Rebecca Hackler. Thanks again for coming in this morning and talking with us.

We are enjoying doing this interview series with Frank Hughes, who spent more than 33 years with NASA, with many of those years developing and implementing training and planning procedures. At the end of our last session, we were talking about the amazing success of Apollo 8, and then the acceleration of the space program as it moved toward the first lunar landing. So, if we can, today, start by talking about how, as you were approaching Apollo 9 and then all the complexities it took to start to train the crew to dock with the LM [Lunar Module], and how that, of course, was moving towards that first lunar landing.

HUGHES: Apollo 8 was a high point, obviously. Everybody came off that [mission] and they're ready to go to work, hard. Some people felt that Apollo 9 was like a backwater kind of thing, but it was not at all to us. Going back just in Earth orbit, it's interesting because once we got going, the LM finally started coming together, the LM that they were going to take with them. That was important. The numbers aren't clear, but it was [LM-]3, I think—LM-1 and 2 were test vehicles.

Jim [James A.] McDivitt was really worried about that flight, he was worried from a couple of standpoints. He'd been in orbit already once, in Gemini [IV]. The Apollo fire had a big effect on him; it had on Wally [Walter M. Schirra], a lot of the guys who were so close to that crew. Jim had a big part in going through the investigation afterward. As we went into it, we had to make sure now that the LM was really going to go, and it was going to go in March, which was just a couple of months away.

People had been working below the radar in the simulator world, suddenly, [we] had to get these two simulators to talk to each other. When you got in the Command Module Simulator and you're looking across to the visual at the other one, you didn't see a real LM, you saw one of these models in the model house, and they'd be moving back and forth with cameras, and vice-versa. In the LM, they'd look out the window and they would see a model of the Command Module.

There's two simulators here in Houston, and a Command Module [Simulator] and LM [Simulator], and then down there [Kennedy Space Center, Florida], we have a Command Module and a LM and another Command Module, so ultimately, there's three of those simulators down there. We're assembling teams of instructors that'll work on all of them. We're still doing Sim-Net-Sims [simulated network simulations], and that's still what they were called at that time. Not until Shuttle did we called those integrated sims. When we did that, it was important that the guys had to work it so that that integration between the simulators worked seamlessly, so when you got in one, you felt like you were really talking to the guys in the other. You see them, everything has to move just the way it is, they're floating against the background of the Earth and the stars, and when you could carry it out. They would come up and launch into a run on

Saturn in this flight, then you separated away, you turned around, went back, and got the LM, just like it was the real deal—except the beautiful view of the Earth down below is really great. All the pictures you see of Dave [David R.] Scott and Rusty [Russell L.] Schweickart, and everybody.

Jim McDivitt and Rusty would be in the LM, that was the plan, and then he [Rusty] was going to actually make an EVA [extravehicular activity]. For an emergency problem, if you couldn't somehow get the hatch open, they had the idea that the LM guys would crawl up over the LM and get back in through the hatch on the other side [on the Command Module]. It's a dicey kind of deal, but that was [how it was] if somehow when you docked and the hatch jammed—or whatever happened. That obviously never happened; that system worked like a champ every time we did it, and it worked that day, too. When we got the LM up there, it flew very well.

Staying with the simulations, then we would do an integrated sim—that is, Sim-Net-Sims—with one or the other or both vehicles. Now, we had a big communication. If you can imagine the lines drawn on the board, you had radio communication from Houston to the Command Module, from Houston to the Lunar Module, from the Command Module to Lunar Module. That's just hard wires, like telephone lines, but it has to act like it's radio. What we didn't do, even later, we never put any [time] delays in. There was only a second and a half [delay] to the Moon, which meant 3 seconds of total delay time. We chose not to simulate that and we screwed up all over in the real world.

After Apollo 8, though, we learned that we just have to say "over," and when you're through talking, it was like you did routinely on airplane operations so these guys picked it up easily. The guys on the ground, the CapComs [Capsule Communicators], they were all flying

dudes too, so it was okay. All the problems we had on Apollo 8, we were always talking over each other because humans just hate silence. They'll immediately start talking again, and by then, they've heard you and they get the answer coming back. It's the first time humans had to really deal with the speed of light as a problem.

This weekend, I'm giving a paper about that, that if you left for a 100-year spaceflight, as you get further away, the delay increases. Mars is 20 minutes, but imagine talking to your husband with a 20-minute delay. You can't have any emotion in it; it just gets stilted. If you go to an hour or a day before you hear the answers back, pretty soon you ask a list of questions and then you get a list of answers and a new list of questions for you. It comes down to a really emotionless kind of thing. You say "I love you," and throw that in the wind [since you will not have an answer from the other person until twice the current time delay goes by].

We were getting that, we knew that [Apollo] 9 didn't have that because we were just in the neighborhood, here, we're 200 miles out, we're not going to be far away. Another thing that bothered Jim and other people in the crew is they were flying off in a spacecraft that didn't have a heat shield. What we did is we restaged the rendezvous that was going to happen on the Moon mission. So they undocked, they would fly away to about 150, 180 miles away, and then work their way back in, going through the rendezvous steps that they would when they were around the Moon.

Of course, we had to make it work, so that led to a thing where—I'm going to draw a picture and you can figure out how to deal with that later—imagine that this is the Earth down here, where the dots are. We're flying along here, and now, when you get out, the Command Module's up here, the target vehicle, and the LM is down here. When you take off on the Moon, now you're in orbit below and behind them, that's called phasing you set up. When you're

below and behind, it means that you're catching up all the time, so gradually, this [tracking] angle is going to get larger. What we always plotted is the Command Module's here and they're down here, and then what they do is maneuvers which would gradually move it up through stages, until finally, you do something called TPI or transfer phase initiation. At 45 degrees, you're looking like this, and the maneuver causes you to come up underneath and you're going to wind up in front of the target vehicle. We'd do the same thing, except now the Earth is down here. It's a bigger thing, but effectively, the mathematic equations are the same. The size of the burns would be different than on the Moon, but the effect is the same. It worked really, really well.

We did it time and again on the simulator, and the way it worked, the LM guys would do it by themselves with just their instructors, and then we would do it together with Dave Scott on the Command Module side. The reason I draw this picture is in order to rescue them—and this has been true for time immemorial (in this business at least)—if it's an active target vehicle, with either one. When you need to make a burn, the LM guys would compute the burn, and the guys in the Command Module computed the burn. It should be almost direct opposite, different, but so much X, +X here, it would be –X here. If one didn't make the burn, if something happened to this engine, then [the other vehicle] he'd do it, and he'd start down to them, or they would meet in the middle.

We've done this on everything until we came to ISS [International Space Station] or Mir [Russian Space Station], where they can't maneuver that vehicle. That's a place in the sky where that vehicle is just going to be there, so you've got to find your way to get to it. There's nothing like we had in Apollo, since both vehicles were active. All through the whole program, we never had to have a Command Module do a burn. It was always just able to be a passive place in the

sky, and they came and got them every time, which was great. It also is good that we knew how to do it and we could do it. It might be interesting, Rebecca, sometime when you're bored, to talk about orbital mechanics. This would show how orbital mechanics works, just take 10-minutes. Then, when you talk about it or you hear them talk about it, you could get something more out of it.

In Apollo 9, that was the kind of thing that was going on. We'd done rendezvous in Gemini, but now we're doing rendezvous for real because we've got somebody out there that doesn't have a heat shield. In the case of the LM, it's the same way, it didn't have a heat shield and it did not have anywhere to get out of orbit up there around the Moon, so you had to go get them some way.

The only problem you couldn't solve is if they didn't get off the Moon, if the LM engine didn't fire to get off the Moon. If it got off into orbit and got them into orbit and then it died, we'd come and get them, we'd come down closer and closer to the Moon with the Command Module and pick them up. We would deal with the rest of it, get the crew out of the LM and still get out of orbit. That is why you had that 20,000-pound service propulsion engine, on the Service Module. It worked. A bunch of things happened—Dave Scott was the Command Module guy, and he and I worked together a lot to make those skills work, so he knew, again, all those navigation procedures and stars.

Like Jim [James A.] Lovell, you had to know the navigation stars, you had to know all those navigation skills, and intimately, you knew all the programs that would compute the rendezvous in the Command Module. A colleague of mine would be in the LM simulator. I'd sit in with him and we'd do the same thing training with Rusty. He was the one that was doing those same rendezvous computations in the LM, so that was how the dual rendezvous happened.

We had these two guys [David and Rusty] working together a lot; Jim was either there or not there, sometimes they did rendezvous sims that he didn't have to be there, but he was good at being there. He was a solid citizen, so he was there all the time.

The work between all of our Link [Division of Singer Corporation] guys and other NASA people to make that play—because it didn't all work every day and we'd find out what was wrong, we ferreted out problems in the flight software that needed to be fixed, we ferreted out problems in MCC [Mission Control Center] software, because they had to compute all these burns, too. The MCC computers had to agree, to concur with what was going on onboard. The MCC would be working with something extra which is radar looking from back here on the Earth. They in MCC were looking at computation of where the MCC thought the LM was compared to where it really is, that was a whole other set of math. We had to try to minimize the errors in our idea where the two vehicles really are around the Moon.

They had these tracking algorithms in the MCC. The algorithms were okay, it was really good, if you let it sit for 6, 8, 10 hours watching the spacecraft [at lunar distance]. But if you maneuvered the spacecraft [translation], then your uncertainty went way up, until you had a chance to track it more and more [several hours], and then your certainty went back up [or the uncertainty went down]. The hardware inside the two spacecraft was so good that the LM and CSM [Command and Service Module] knew pretty much where they were all the time. The ground could have waited, they would have made a computation and then fired again. But basically, the spacecraft became prime for the first time. These spacecraft, you can imagine, were autonomous. They almost could get back to the Earth without any help, and in fact, that was an important part of the work we did to make sure that they could get back by themselves.

We talked about earlier the term "cislunar navigation," where you could actually navigate all your way back and get home without any help, somehow, if we had enough communication blackouts. We could never come up with a scenario that would give us total no-comm, but if it happened, you could do it, which makes you feel good. We went through January; it was a little bit quiet, because Apollo 8 had taken everybody's energy away. It's some of that, but late January, all of February, we were simming all the time and going crazy with that. It was fun in a way because the Apollo 10 guys are in the simulator, too, so now you had two teams that were working on this—and [Apollo] 11 was there, they would come in. It's almost like 9 had all the primary simulator time, and then you had 10, and then 11, because they're just the priority of what's going on. [Apollo] 11 got a lot, probably no less than 10, even as early as that. It wasn't that it was going to land; it was just the first one to try. [Apollo] 10 was going to go but not land, and that gave it a whole other set of things to do.

As we went through this period, the 9 team really pulled together and they were ready to fly. When they did fly, it was interesting because that's the first time after Frank Borman that somebody got sick. Rusty was really sick; he was almost incapacitated for a couple of days. He certainly got better, but for a while there, they were talking about never even having him go outside, no EVA at all. This is in real-time, so you know there's some other people talking about it. He was just debilitated, really sick. They [MCC] were worried about him barfing in the suit. Finally, he pushed through that and said he was ready to go. He was limited to get outside and stayed on the "front porch". He was on the porch of the front of the LM and did a few things out there, housekeeping kind of stuff, that was it, and then he got back in. There was never a chance to scamper up over back to the Command Module on the outside.

They still did do that EVA and Rusty got pictures of Dave going out from the CSM, where pieces of material that were attached outside that Rusty was going to grab and bring in. So they did pressurize the Command Module later, after they'd dumped the LM, and he got those things inside. He [Dave] has one of those cast iron stomachs, it just didn't bother him at all. On his flights, which was Gemini VIII and this one, he was in good shape, and then on [Apollo] 15 as well. When this Apollo 9 [mission] got going, they flew successfully, they got in the LM and went off into the distance, everything worked perfectly, swung back in. Everybody's thinking really good thoughts about 10, now, you know, that this sucker [LM] really worked. The LM performed beautifully. There were some small things, but they were trivial.

It told us a lot about the simulators—it always does—and this is the first time now, this is the third Command Module we had seen, and so we knew that there was almost nothing we had to fix on the Command Module Simulators, which is good, and we had one in-flight LM on Apollo 5 that we flew. At the end of this mission, the MCC lit the ascent engine and let it go. It flew on to South America or somewhere, and crashed in the jungle, or God knows where it went. That was one LM to give us useful simulator information, but now this one with the people in it, we got to see the environmental control systems and the navigation systems. That came together pretty good, so we were happy with that the data that we received.

As soon as 9 landed, the 10 training really increased, so they became the top priority and started going along. The crew of 10 was more rigorous. They trained a lot. They took every chance they could get to train—not that 9 didn't—but the 10 crew really turned up the heat even more, and it's all three of them. [Thomas P.] Stafford—we did earlier flights like Gemini, he just had it under control—now he's flying with the two guys that really understood the software, so I mean, he hardly knew anything about that computer stuff. He said, "[John W.] Young has

got the Command Module computer, [Eugene A.] Cernan's got the LM computer," and he was going to fly. "Just give me the stick."

WRIGHT: Spoken like a true pilot, right?

HUGHES: Yes, exactly, that was something that you go on, in the training. He came out of an era of airplanes where they were not so computerized—it was like a flying stovepipe, you just pointed and it would go—with Gus [Virgil I. Grissom] and all those early guys. Where these guys, Cernan and Young, were from F-4s [Phantom jet fighter aircraft], which had much more computerized. Now, we're talking about the Vietnam era. They flew and they were used to having a computer of some kind that they would talk to and deliver weapons or navigate back home.

Different software and different way to talk to it, but they understood that that's what you do, and they just spent the time learning how to do it and got very good at it. That stood them very well when they were commanders, because now they knew all that, and they would watch over whoever was their Lunar Module pilots, and made sure that they did it right. It was working pretty well, plus I think 10 was an interesting one. They had more fun. They were really much more relaxed. They weren't going to land on the Moon, as much as they'd love to, they were very comfortable with the fact that we're going to the Moon, somebody had done that already, they were going to jump into the LM and do a rendezvous, and somebody's done that already. So you can see that you begin to have confidence in the hardware that's going to go through all those phases.

Meanwhile, the simulators were working really well, that we had, piece by piece, overcome all the difficulties. A simulator is such an amazing piece of gear because if you want to simulate a tank, you have a piece of software that just acts like it is a tank, and it pretends to be a tank, which means it's got fuel in it. The fuel is so many pounds, you compute how much it is in terms of weight or mass, and then you compute the pressure and the temperature in the tank. Then you have a quantity gauge, so as you pull fuel up, if you fire an engine, then your quantity gauge changed. That value is sent to someplace else so that it shows up on the computer displays.

In all these cases, there's all these separate little pieces of software. There's all these pieces of hardware that somebody bolted together, but now we've got all these pieces of software. They generate telemetry, and that all has to be scooped up by another piece of software, and send it to ground like the on-board system would do that. All the ramifications of that means that gradually they got it right. It was pretty good from the beginning; it wasn't good enough to satisfy Gus when he was trying to fly because that was really an immature time, but over those two years since '67, we had been able to get it really, really working right. When they came back, 9 came back, they couldn't say enough about the simulator. They felt that they were ready, they really had been there before.

There were things that happened, getting sick, things happened where the visual is not nearly as good as looking out the window. Well, that's not going to be, it's never going to be the same, looking at the Earth go by, especially with the ever-changing clouds and weather down there, and the Sun glint on the ocean, and some of the things they talked about. That's just true, it's never going to be there. But, they had such a good time in the simulator and better in flight.

Apollo 10 was interesting. They were pushing the edge of the real flight software now, and they were using it and pushing it to the extent possible, they could do whatever they could do. When they flew—and I was very close to that crew, it was a pretty good deal—we had a great time. I left two days before launch, I went down to Houston, was in the Control Center again, in that Flight Director SSR [Staff Support Room].

The one thing that happened back in Apollo 8, nobody talked a lot about this, the crew had a hard time sleeping because we had a procedure called Passive Thermal Control [PTC]. In orbit, the spacecraft gets hot when you're in the sunny side, but then it would go into the night side and cool off and so on. Once you leave the Earth, you get out to the point where there's no shade, you're in the Sun all the time. What we did is there was a barbecue mode, they called it, we'd point the nose of the spacecraft north, toward the north celestial pole, and then we'd spin it so that the Sun is always on the side, but we spun it. When you did that, you got to a temperature that was reasonable because each side was cooling off a little bit on the shade side, because you've got this +250 degree F on the Sun side and –250 degree F on the other. That worked pretty well.

In Apollo 10, I just woke up to a problem because I've been through this procedure where we do it, point it to the north celestial pole, and then fire the jets. There's a thing called a deadband. It's like if you can imagine that you're the spacecraft and you say, "This is roll and this is zero," let's say, if you're looking up. Let me change this to pitch, just for a minute. You'll set a deadband that says that the spacecraft can coast over here about 5 degrees, and then the jets fire and send it back, so it'll go through zero, and go to –5, and then the jets would fire and send it back. It just oscillated back and forth, and you'd do the same thing in yaw, and so on. It has to stay within + and – 5 degrees deadband of the angle you set for it.

There was a problem, when you're spinning like this, there was a thing called gimbal lock, in that if you went far, it would dump the inertial platform. It was a weakness in the Apollo hardware. It torqued the platform so then you'd have to go through and realign that platform to get the unit set up again.

This is called a deadband, a deadband just means—even airplanes have them—they could be much tighter, you could tighten it and say, "I want them to do ±1 degree, it could go ±10 degrees." This is going on in all the axes except roll because now they're rolling, so they just turn that one and make that one zero; that just goes all the time. They were trying to go to sleep the first night, and it was banging, and these jets are big jets, I mean, big, 100 pounds each, but they're right outside the wall there, so they go, bang, bang, and bang, bang, like that, so it was keeping them awake.

I had thought about this since December, when we were flying Apollo 8, and I went and talked to a guy at MIT [Massachusetts Institute of Technology, Cambridge], Malcolm [W.] Johnston, and I said, "We got to do something about this." Here's the deal, if you have a spacecraft like this, imagine this is a Command Module. I'm going to give you a torque pulse. This is my little Command Service Module [holding a plastic model]. If you set out this pitch or yaw, it means you could go only 5 degrees, and that's what they're doing. It does go a little far each side. That's not where the spacecraft is rotating. Just because somebody drew a line through here, if you ask it to roll, it doesn't roll around that axis. You'd have to take all of the different pieces of fuel and everything in there, and by itself, it's going to find a different axis rotation.

Just think about this. If you throw a ball for your dog, it rotates, but it may rotate around the center because there may be a chunk taken out of the ball so it'd wobble. It's wobbling but

it's not really, it's just rotating around its natural center of gravity at the moment. Malcolm and I actually went to a guy in the SPAN, they called it then, the Spacecraft Program Analysis Room, and said, "We want to try something with the spacecraft." And basically it was this, that you would open these deadbands wide, and do the same thing except then when you turned it loose, you didn't care if it went 10 or 15 degrees over here, but it would find a stability point that it liked, and then it's going to rotate around that place, today. Tomorrow, if you do it again, it's going to be at a slightly different place because you've used up some fuel, oxygen, everything's getting used up. It's not going to go bonkers, it's not going to go some crazy place because it becomes a gyroscope—once you spin it, it's going to try to stay where it's natural spin access is.

Along with the SPAN [Spacecraft Analysis] guy, I went to a Program Analysis meeting with George [M.] Low and I said [briefly], "We have to allow it to find its own axis of rotation."

He says, "Can you do this?"

I said, "Yes, we're going over to a simulator now, we're going to develop the procedure. It's just a modification of the PTC procedures we're doing," and we did it. Basically, we set these deadbands at 20 degrees out here, the pitch and yaw, turned roll off entirely, and then so what they did is they stood on its end and then the procedures said, "Accelerate until you hit 1 degrees a second." That's a pretty decent rotation rate, so it means 360 degrees is going to take 6 minutes to go around. We did it on the simulator and it worked—this is the Command Mission Simulator in Houston I was using because that's where we were—and talked about it and watched it. It worked perfectly even in the simulator. The CMS did not have a very good simulation of all the fuel masses but it had some. It just stayed there and did its thing. It didn't rotate around this line that somebody drew down the middle, but it found a place somewhere

else. There was enough simulation of different weights on various parts of the vehicle to show that it worked and it worked.

We went back and wrote the procedures up and took it back, and went through George again, and said, "We think we've got it, we're ready try right now. Can we?"

George said, "We'll do it now before they're ready to go to bed tonight." They were coasting; they just had a lot of dead time, they're in the second day out. CapCom radioed up [those procedures] to them, I was in there with them, and they said, "Frank tried this in the simulator and he says it's okay."

John and I had confidence with each other, and he said, "Okay, we will do it." They set it up and they did it, and it started spinning, and it went out about 15 degrees, and then it just kept going. No jets because it was never hitting those other deadbands, it was not way out there, and it just was stable and they let it go for 56 hours. They didn't do any midcourse corrections or anything, and they went to sleep that night, slept like lambs for two nights in a row. The only time they had to stop it was when they were getting ready to get into lunar orbit because they were about 20 hours out by the time they did this. It was great, so after that, everybody [every flight] did this kind of procedure. We made a name for it later, for Shuttle, this became Adaptive Attitude Control, where you don't try to rotate around the X-axis or the Y-axis or the Z-axis, but some intermediate axis. But never would do it.

In new vehicles, they never tried it again, so that's still something that I have to push or let people know, that if they were to let the vehicle rotate around the natural angle at the time, you'll get there to where you want to go, but save a lot less fuel. Even for short maneuvers, just fire and let it drift itself over to where it's going to be, and then correct it down, as opposed to strong-arming it to the place. Like I said, just because somebody put these X/Y/Z lines on here,

doesn't mean anything to the vehicle once you put in all these mass cons, if you will, mass concentration of fuel and oxygen and communications gear. That became the standard, so all of the Apollo flights, all PTC now was done in this procedure and it worked like a great—we had a good time on that one.

WRIGHT: Let me ask you while you're talking about that, because in your description, you made it sound very casual, that you talked to George Low, is this something that you felt that you could do with someone that was a high-profile, high-ranking decision-maker?

HUGHES: I was never impressed by anybody, anyway. That was just me. I think a lot of people had a lot of trouble. Malcolm Johnston didn't even get to go to the meeting to talk about—he had him come out and they were not going and I said, "No, he's got to come with me, he's been working on it with me." First of all, I'd see these guys at the simulator, they'd come down and see how they're doing, and everybody was kind of shy about things like that. Somehow, I just didn't have that in me. I talked to everybody. I talked to everybody in the line at Kroger.

WRIGHT: A lot of practice. I'm just curious because it didn't seem that there was a specific protocol for you to have to bounce these ideas off—

HUGHES: There was a protocol, I had to get on the agenda, first time out, but I went to a guy I knew who was in the Spacecraft Analysis Room, and I said, "I've got this idea…

I talked him through it, and the guy says, "You're probably right, let's give it a try."

Then, we went in the simulator and did it, and we were able to come back and say, "It's working now, it's working in the simulator. It doesn't mean it's up there, but I think it's a pretty good chance that this is going to be good; it's going to be better in the spacecraft because you've got all of the different mass concentrations. It's going to find its own natural rotation spot." Every one is different and every night it was different, but it worked, always. Everybody was worried that with the cone out, like a precession, it would get wider and wider until I finally screwed up the navigation system. It didn't; it just stayed in close but not on it because the spacecraft didn't know anything about the X-axis in a real thing. If I threw this thing through the air, it would spin, but it would spin around whatever its natural axis there.

WRIGHT: When procedures as this one made its way into now the flight plan, talk about the process of effect, that this is a major change, and how everything got updated.

HUGHES: It was funny; a lot of people in the procedures world were upset that somebody would do this. Not that we didn't do it all the time in the simulator, but I had to go through the physics and explain what the hell I was even talking about because, Lord love them, they were engineers. They're electrical engineers and they never had a course that talked about rotation and bodies and physics rotations. It was helpful to just sit down, and before I left Houston, I sat down and had talked to two people in the procedures world. They put it in because we proved something, but they didn't have a clear idea what we were talking about. As much as a couple of hundred of their compadres, then you get to leave that alone, it's like planting a virus in there, and then it would spread and everybody would get an idea. It was that kind of process, kind of like "infecting them."

Going back to George, I didn't know George, I was in a lot of meetings, but he'd seen me at the Flight Readiness Reviews. I was talking for Deke [Donald K. Slayton] [in those meetings], and so it's no big thing [for George] to find out, "Does he [Hughes] know what the hell he's talking about or not?" Somebody had to give him that information offline that says, "Probably they're right." Once you said it, give people this idea, everybody starts thinking about it. I'm just saying, somebody drew that line, but the spacecraft doesn't know about it. You're trying to force it to rotate around that axis because that's what we put together, but it's going to cost you a lot of fuel and it'd make a hell of a lot of noise if you're trying to sleep. It does, really.

WRIGHT: Yes, because it wasn't just for the astronauts, it had much more of an impact on the fuel use.

HUGHES: Exactly, exactly. Apollo 10, they were fuel-fat for the rest of the flight because they didn't use any going or coming. They had plenty to use to go down and rescue the guys, if they had to, and get the LM back if they had any problem with engines. The mantra we went with was, "Bring all the fuel home." Let it burn up in the atmosphere. Save it all for later.

WRIGHT: There seems to be a hidden joke with the crew that they would make the decision whether or not they wanted to go down or not, so was that something that you all tossed around as an idea, that they really wanted to land?

HUGHES: No, they knew they weren't going to land. It was funny at the time, they certainly could have, but that was not their mission. That's a whole other thing, where they uncovered a whole lot of things with that separation, when they did abort stage on the LM. I was going to talk about that a little bit. If you think about the steps they went through—because we actually set up a problem here that caused all the computer problems on 11, and it was because people did such a good job, that caused other problems. When they got down—remember the deadband, we talked about it—they were going to simulate an abort stage, meaning that something was really wrong with the descent stage, when they had used it up already, but then they blew it off. When they did punch off the decent stage, the autopilot had a different attitude it wanted to be at. They were at this attitude, and then when the spacecraft separated out, now it's so light that it did a big maneuver because it was trying to get back to the attitude it wanted to be.

Tom had been taking over for this staging thing just in case. When he went back to auto, thinking, "We're done now, we're just starting navigation, going through the rendezvous to go back," he didn't zero out the stick. Remember that thing where I said I'd like this attitude to stay here? They didn't do that, so when he gave it auto, it immediately did a big maneuver. That's when he said, "Get that son of a bitch!" These quiet comments that'd come down from the spacecraft. It was that, that suddenly, they were making a—now, it's so maneuverable because it's so lightweight, this big, heavy descent stage is gone, but it's close, it's not very far away. It's right around the neighborhood, and that's what they worried about, that they'd hit it. As they turn around, apparently they had maneuvered away pretty decent, but you don't know that when something's making a lurch and change of attitude.

In the separation, remember I told you that the ground tracking was slow to come together from lunar distance. When they separated on Apollo 10, they separated behind the

Moon, and then the LM did a small burn to start down. They came from 60 miles down to about 9 miles; they came down close to the Moon and then went back up, if nothing happens. They came down, so they came around the corner, and the two vehicles appear, but now they knew just where the Command Module was, but they didn't know for sure where the LM was [because it had made a maneuver]. All their tracking filters now kind of blew up. If you imagine, there's a big cloud of ignorance about where exactly the LM is. And, it's only 45 minutes in the front before they start burning again if this was a landing mission. They didn't have time to get a good idea where the LM was.

They went through that mission successfully; we went with the Command Module's idea, and the LM's idea of where it was internally. Everybody was good with that during the flight. After the flight, MCC people said, "We've got rendezvous radar there, we know exactly where the Command Module is, so if we turn the rendezvous radar on, when we separate, then we have a good line of sight between that tells us where the LM is now." So during Apollo 11, when they come around the corner [of the Moon], they did that. That was all well; they knew just where the LM was. But they forgot to turn it off. Nobody in the procedures world thought to say, "Okay, now we know the LM state vector, pull the circuit breaker." So on Apollo 11, we did not kill the rendezvous radar and just concentrated on the landing radar. That is the story of the alarms during the landing

Now, you're coming down in the front of the Moon and you're laying on your back, face-up, you're looking at the stars, the engine is forward [holding a model of the LM]. When they start doing powered descent, PDI, Powered Descent Initiation, what happens is imagine if I'm going toward you, and you're in the landing site over there, you're going across, as soon as I start firing against it. I'm using fuel, but I'm slowing down, which means that I'm going about

2,000 feet a second forward, and now I'm going to start losing that speed. As soon as I start firing against the direction you are traveling, the orbit starts to sag downward. Immediately, they start tilting down, too, so now you're coming across the ground, but the engine is not just firing this way, but it's firing 45 degrees. You've got a component down as well as one forward, you're holding up the velocity here as well as here, so you maintain how much height you get. It just comes down like that, further and further and further, until when you're at about 500 feet, you're standing on the flame.

That's when Neil [A. Armstrong] looked around and there was a problem with a boulder field, and the boulders were not huge, but they were big enough so that we could not see them in the photos we had of that area. They were just below the pixel resolution, so it looked like just a gray area, or fuzzy. It turns out he didn't want to land on it, that's why he stayed up higher and skated over across that, so just like a helicopter, he would just keep moving forward. If you didn't do anything, the engine is still firing to keep your altitude up, but he just scooted forward and brought it down beyond the bounder field.

That's a different thing, but here's the idea of coming down, when you come over like this, your rendezvous radar acquires the ground, and your landing radar is telling you what's going on. In Apollo 11, it is also doing the rendezvous radar, so that's why the computer was overtaxed, so that all those things they had inside the computer—it was not a very big computer—it took 2 seconds to go through this list of jobs it had to do. It was called a wait list. It was like a to-do list, and so it would go through all these things and it was prioritized. The most important things would get done first, and then, if you couldn't do everything else, it just wouldn't do them. It would go back to the top and again come down through it all. If you were the computer, you were looking at this, it knew that it wasn't doing rendezvous, it was doing

landing, so it would throw out the rendezvous radar information. but it would ring an alarm and just notify. It says, "I can't do all this stuff," so this is 1201 [alarm]. You came down further and further, and then you start going from once every 2 seconds to once a second [through all the items is needed to do], it's just what's built in, so now it's getting more serious.

Now, the wait list has more things being thrown out, so that's it accelerated to a 1202. [Computer was saying] I'm having more problems, and I'm processing everything that's important here, but I'm not doing some other things on that list. You'd have to know what that was, deep inside the computer, to know exactly what's going on. But, it managed. On [Apollo] 12 and every flight after that, all they did is they got that information about where the LM was and then they pulled the rendezvous radar circuit breaker, and you never saw that problem again.

It's one of those things where they had a great idea, and it did work, find out because the Command Module knew where it was, so then the LM got to know because they used the rendezvous radar. After 10 minutes of that data, you could just pull off that breaker, shut down the rendezvous until time came to launch and use the rendezvous to go back home.

WRIGHT: Between 10 and 11, were there more or a whole lot of different procedures? Things that you did?

HUGHES: A lot of procedures, yes. There was some from 9 to 10; there were a lot from 10 to 11, like the one we're just talking about, here. When it went through that, the procedures, I think I told you, John [W.] O'Neill and his guys were doing, on 10 and 11 and probably every flight after that, they were always in the cockpit the night before launch, and they were putting pen-and-inks into the flight books. They didn't have time to get them printed up; they just went with

it, which is true on every damn Shuttle flight, too. I don't think there's any time we've launched without pen-and-inks of some kind. Sometimes, they were just for fun. They would go and put stuff in that was funny, that was risqué, that was whatever else. It's a fun group. It's like you offset all of the danger of what you're doing by humor and by lightheartedness. Of course, the people who didn't handle that didn't go again, they took themselves out. Which is okay, that's the way it should be.

When these guys get hired, I always had the algorithm that when you came into the astronaut office after you've gone through learning how to fly high-performance airplane, flying 1,000 hours, getting into test pilot school, succeed in test pilot school and graduate from there, and then get selected to the astronaut [corps], which would then move you back to the first airplane you ever flew, a T-38 first jet [trainer] airplane, probably half your flying friends are already dead. It's taken them out, that many times. Not to their fault—the airplane malfunctions and all kinds of other stuff happen. If you're over Vietnam or anyplace and they get shot down, there's so many different things—they think they are semi-bulletproof. Many, probably, they'll just begin to say, "This sucker's going to get me, the numbers are coming." That's why for Jim, on 9, he had already made a promise to his wife; he wasn't going again after this one. That was it.

WRIGHT: Talk about the trainers and the people that you were bringing in to help.

HUGHES: It was an interesting thing. The people were really, really good, and many of them, let's say half of them or so, might have been pilots, private pilots, mostly. They were just wannabe astronauts. You had that kind of people who had potential so they learned how to fly

everything there was. They knew everything about that, they'd know the procedures, they knew they could get in and land on the LM, they would know the launch procedures, and so on like that. They would do a rendezvous, they would do a launch on the Command Module, and get in there and turn around and dock, rendezvous and dock. They just got to be as good as the astronauts at what they were doing. We had a chili [cook-off] team later, and this is back in the era of Shuttle, but you know *The Right Stuff* [written by] Tom Wolfe, we had a chili team and called it "The Wrong Stuff." Obviously, we were close but no cigar, so we had the wrong stuff. They had a patch, the patch was "it's NADA." It looks like NASA, and it says, "No, it's NADA."

"What does that mean?"

"Nothing."

"Yes, but what does it mean?"

"It's nothing." Which it does, in Spanish, it means nothing. It's a nothing patch, it's literally—everything was a send-up of this whole thing, this patch doesn't mean anything. We were the "Wrong Stuff" team.

WRIGHT: Were you involved in hiring the new people coming in? Were you at that level?

HUGHES: I never hired, no, I was not at that level. When I went to Houston to do the Apollo 11, I was a GS-11 [General Schedule pay system] when I was 24.

WRIGHT: Amazing.

HUGHES: Yes, yes. It was that kind of thing. Other people did it after me, they would take these guys down, two guys came down, Joe [Joseph E.] Sundra and I did Apollo 8, and then there was four once there was a Lunar Module. We went through that because you'd have two Command Module and two Lunar guys, and then you'd do 12-hour shifts so somebody was there all the time. They got better; some people were not as good, just it's a human nature thing, some people excelled, some people did really good, and some people found a way out of there. We had a couple of people that came in and that we would literally say, like, every job you've ever been in, "How the hell did this person get in here?" People just excelled, they'd really apply themselves, and there were so many things. Some people were good at software, some people were good at hardware, so you found your niche and did something. It was really, really good.

WRIGHT: I remember reading, as I was looking for some information this morning and yesterday, that I think Mr. [Stanley] Faber had talked about that the simulators in the systems in Florida and Houston had to be upgraded so much at this time period that it was a task that was much more than a 7-day, 24-hour effort to do because it was just constant.

HUGHES: It was all the time. We worked third shift, second shift, because they'd put a new mods [modifications] in and then we'd have to check it out to make sure it worked the way it was supposed to, and then people who checked it out are the people that knew how the vehicle worked, so you'd have to work all these crazy hours. Yes, I was not married during this time and that was a good thing. It was tough on people who were married. I don't know if some didn't make it as married couples, because of all the work. It was interesting.

On the LM simulator, remember I talked about the Command Module visual with the lunar models and films and so on. In the LM, it was a different issue, it had a landing area, they had a model of the landing zone, that's about 10 by 15 feet. It's a fiberglass model of the Moon. When it was done first, originally, it was just made-up Moon, but when we got into landing on it, they actually had fiberglass models because Lunar Orbiter had done so much good photography that they would make a chunk of the Moon and it would fit up into this Landing and Ascent [L&A] device. If you can imagine, the L&A is a little bit bigger than the size of your office, here, a big, heavy-duty structure

You know what an X-Y Plotter is, in the old days? X-Y Plotter? Okay, this is a big X-Y Plotter except the paper was the Moon, and it was hanging upside-down. It's looking down because at the magnification you're talking about in this device, dust on it would be big. It's hanging upside-down, and they still blew it off using compressed air regularly. It was painted really well, it had the right craters. The landing spot where you're going was two-thirds of the way down the length of this L&A surface That's where you'd set it up—if you went further and so on, but within there. You came down approaching the Moon and there was the film-related mission effects projectors showing the Moon below, but finally, when you get down close, all of a sudden, this L&A appears.

The L&A was this big X-Y plotter moving back and forth, and there's two cameras mounting, looking up, and that's one for each of the two windows. In front of the cameras, there was a prism that would rotate, it was a tiny, little thing, but it changed where you're vehicle was looking. If the vehicle looked at these little prisms with up, down, left, right, as though when you see the picture inside the LM, there's the LM, and if you maneuver around, it would maneuver like you were really doing it. You get the whole experience, no dust, but the dust only

kicked up when you got down close. It was a really good simulation, but we were young, and so, that L&A was just so tempting.

You know what cellophane tape is? You grew up with that, and you remember Magic Tape when it appeared. You may not be old enough to know that. The 3M [Company] came out with this new tape that you couldn't see once you put it down. Meanwhile, this is Florida, and so these big-ass Palmetto bugs, that in any name you call them, they're cockroaches, about 3 inches long. We captured one and we put it up there and we'd tape it to the lunar surface on the L&A, about 2 inches away from where they're going to land. It's still alive, and it's just trying to get away, that's all it's doing, antenna's waving and the legs are darting.

The first instructors to go in would never say anything, get the simulator ready, and the first guys would come in and they'd jump in and they'd fly down, boom! You look out the window, here's this gigantic captive thing writhing in the horizon. There was stuff like that all the time.

When [Alan B.] Shepard was flown, somebody put up a nine-flag, sticking out of a hole like it was going golfing out there. There were so many things put out there. Sometimes, it was just—the Michigan banner—like if the team won the day before, there was a celebratory—somebody in our crowd was Michigan also, and so they'd put something out there. There's a lot of this stuff.

In the Command Module, the same kind of thing. Each one had two windows—remember I told you, you'd come down and dock, but actually, when you docked, now the magnification is so much that it would jitter because there are little tiny servo-wheels that held it in place, positioned it, but now you could see that you were so close that you could tell that there's phony things going on. There was a system that just dropped the 35 millimeter slide in

place somewhere else, but when you switched to that, now you've got a solid image of the LM from the Command Module, or vice versa. When you did that, it was just a 35, so there was a picture taken of the top of that docked model.

It would happen that it would come in and you did soft dock—remember, we talked about that—then, when you throw the switch and bring it in so you get a solid dock, that's when the 35 millimeters light up. But again, we're young; a lot of other 35 millimeter slides exist in the universe. It was everywhere between good-looking ladies in various stage of dress, and all that sort of thing. Apollo 10, I told you, had a good time. The guys fixed it up and they gave this really beautiful girl on the right side, where Cernan is sitting, he and Young are over here, but they gave a really fat, fat, nasty picture in front of Stafford, and these guys are going, "Wow," and he's looking at something, that's just totally different from what the other two are seeing. He said, "What are you guys talking about?" Finally, you could hear him crawling over to the other guys to look out his side of the window. It's like craziness, sometimes *Animal House*.

That's the thing, talking about *A Funny Thing Happened on the Way to the Moon*, I have a lecture that I give that talks about that just crazy stuff. The co-ops [cooperative education program students] used to call and said, "If we buy the beers, will you tell the stories?" You can get into the scatological things, and it was crazy. In Apollo, there was an interesting one. They used bags to urinate and go to the bathroom, if they needed to. There was a toilet design that you sat on this—the idea with the designers—that you sat on the wall and you put all your apparatus inside this "device" and then you would crack this valve, and it went to vacuum. They said, "Nobody's going to do that. Pull a vacuum?" You can imagine just turning your whole body

inside-out in it. That was a big laugh, but they said, "Take it out, we're not going to fly it, we're not going to use that."

WRIGHT: You had mentioned, in fact, a couple of times that you felt Apollo 12 was the best-trained because you were able to apply [lessons learned], and you had had time, and things seemed to fall in place.

HUGHES: It's really true. When 12 came along, now, they were in training before 11 went, and it did a bunch of good things. First of all, they didn't have to land on the Moon the first time. Immediately, all of the brouhaha went away. They were really good at it—they were nailing them dead. Every time they'd land, it was done well. They had a special thing, they had to land in a specific place so we could find Surveyor [3 unmanned lunar lander]. We had a Surveyor there right beside them, it was a mock-up from JPL [Jet Propulsion Laboratory, Pasadena, California] that they brought down to KSC, so we put it on a 30-degree slope, just a plywood platform, and I've got pictures of that. In that history of simulation that I gave you, you can see it. They would get in the Command Module, they'd fly into orbit, then they'd get out and both of them would get in the LM, and then, Al [Alan L.] Bean and Pete [Charles Conrad] would un-dock and come go through all the steps all the way down, and land, and then they'd walk over and they would screw around with the Surveyor. They would go up in a mock-up of a LM, a big one—and then get in the spacesuits and come down out of that and mess with the Surveyor.

You had to cut a cable between two parts, a camera and a computer. That cable was inoculated with germs, and they wanted to take it home and see if the germs had survived in there. They did, by the way, after four years on the Moon or something like that, these suckers

were still viable. If we ever got planted in here on the Earth from somewhere else, it is very easily done. It's just amazing.

They were good—Pete was a good stick man, anyway. The vehicle's working right, the simulator's working right. Yes, they didn't miss a lick, in terms of getting ready to go. They were more fun. It was interesting, Dick [Richard F.] Gordon was now the Command Module guy, and I even laid a bet on him that he could not see—he was going to try to use the sextant and see the LM down there, and he did. I was home, I was off-shift, I didn't go to Houston this time. I was still working on [the Apollo] 13 guys, in fact, by the time 12 was flying. I could hear them in the air-to-ground, he says, all of a sudden, "There it is, I've got it."

I lost a bottle of Chivas Regal on this, and I said, "That's the most stupid bet I've ever made—I don't know to this day whether he did or not. All he had to do is say he did [see it] and I'm done for."

WRIGHT: You lost before it ever started.

HUGHES: I didn't say, "Bring a picture back." I bought it and screwed that one up bad. It was that kind of thing, we were more relaxed. They just were able to step into the thing and get going. They landed right within 150 yards of where they should be, and they nailed it then because it was on this side of this crater, they flew across and landed on the other side. It was great. That's the only problem with that one, is they screwed up the camera, the movie camera, soon as they got out, they accidentally—Alan pointed it at the Sun, boom, burned up the Vidicon [camera].

WRIGHT: We learned a little bit about lightning, I guess, on that launch.

HUGHES: Yes, that was when I was there. That's the first [launch] I saw in person. It was raining so bad, the [cloud] ceiling was about at the top of the Command Module, so they took off, and it just went right through the clouds, you could hear it all the way, but you couldn't see it at all. It was only after that you saw the lightning. We learned a lot about ionic transfer, with the discharge. There was no lightning before that, but inside of a storm, there's a certain amount of charge built up. It's like you a hung a big copper wire down, from the middle of the cloud, down, because it was the ions in the flame, and the thing just jumped on it and sailed all the way down into the ground and hit the pad. It was like, "Whew, that was a hell of a thing."

Then they start thinking what that did to the vehicle, and of course, it knocked everything catawampus in the Command Module, but the old Saturn just growled along. IBM did a good job of protecting it, and they flew right into orbit without a lick, dumped them in orbit, and they held them steady while Dick Gordon did a [platform] realign and got it all back together.

Sixty-nine [1969] was a hell of a year. There was so much to do and so many people worked so hard to get it right, and we learned so much. Every time, every flight, we learned a whole lot that was immediately applied to the next one. After that, everything slowed down. I shouldn't say that because in '70, [Apollo] 13 came running along and that crew was ready to go just as good as 12. You would have said that they were just as good. T.K. [Thomas K. Mattingly] was wonderful in the Command Module, knew everything going on, Fred [W. Haise] was the LM guy with the computer systems and navigation, and [Jim Lovell] could fly the box it came in, and land it. He was a really good stick man, too. He had a lot of stories that he tells about different incidents he flew, that he got himself back.

[Apollo] 13, when we fell into that one, I didn't go to Houston. I had an interesting thing when that week started, we went through, there was some updates but very much the flight software that we got for the Command Module was almost the same. The LM got some updates after 12, but it was really an easy sail. We moved through it, the crew had already been in orbit sometime before, the commanders, and then the new guys, Haise and Mattingly, were dreams to work with. They were really good and knew their stuff, and it was all good.

And we went through the measles thing, and that was a disaster. We could not believe that they pulled him at that point. We were all saying, "Just go next month, just go next month." Because the Moon is always there, it comes around, and it's not like we're landing like Apollo 11. [President John F.] Kennedy's satisfied; he won't turn over in his grave if we wait a month before we go back. Let everybody get off for Spring Break; the kids were getting out of school.

But they went. Of course, when they put [John L.] Swigert in, I was part of the team that had to get him geared up because he knew he wasn't going, so he had been screwing around, literally and figuratively, up and down the beach, and had a good time. He knew he would be on [Apollo] 16, that was his thing, and he would have been fine on that flight.

He'd been missing in action some, and really he was just scared to death of screwing up, the typical thing—"Don't screw up." We had him in there 14 hours, a couple of days running, going through things. Just getting him back up to speed to what he could have been if he'd been training hard all along. The backup crew didn't get a lot of training, either. Gradually, as you get close to launch, the prime guys take it all. He got in there and he performed well along the way, so it's okay. He did a super job and I'm proud of him.

I was really sad to lose him when we did lose him. That was a whole tough deal. He was a great guy and he would have made a really good flight commander someday, but didn't get his

chance. After that mission, then it was a hard act to follow. That's when he decided to go back to Colorado and run for office, which he won, but never got to take the seat. I don't know when he knew he was sick because it's one of those things where I didn't talk to him before he was gone. You read in the papers, once he's gone, it's like, "Holy crap." That happens every day now, I'm used to it now, but not at those ages. Today, you have to read the paper to make sure that your name is not there, it's okay.

WRIGHT: That's a good thing, yes. That's true. What was your role during Apollo 13, and where were you when you heard the news?

HUGHES: It's interesting. I grew up in Montana and went to a Catholic preschool and high school, and when I graduated there, they put the hard sell on me to go be a priest and I said, "Oh, I've got other plans." But about 30 percent of those classes, the women went to the nuns and the men either went to be monks or priests. It's an Irish-Catholic town. One of my good friends, a woman named Sharon Feeney at the time, had gone off to some order in Des Moines, Iowa. She had done her thing. She got a degree in physics, ultimately, but she was teaching school in Des Moines, Iowa. About two weeks before Apollo 13, she gave me a phone call that says, "This is Sharon."

I say, "Great, how are you?" I haven't seen her since graduation because we've just not crossed paths, so now it's a few years out.

She says, "We would like to take our senior class girls down to see the launch of Apollo 13. Could you get us a hotel room?"

I said, "Are you kidding? At this stage, you couldn't get a hotel room in Tampa, let alone up and down the beach, here." I said, "But two weeks ago, I signed the paper for a house, I bought a new house." I was moving off the beach finally; I was going to live in Cocoa, a little town on the mainland. Actually, it's a place called Rockledge. "I have a three-bedroom house." I didn't have any furniture when I bought it, so I bought a refrigerator and a new bedroom set, and I said, "I have nothing on the floor except what I sleep in and bookcases and my desk." I had a lot of books, and I said, "but if they bring sleeping bags, I got a lot of space whole empty rooms, we can put them up."

Two nights before the [launch], on the weekend—we launched on a Saturday—this 42-passenger bus shows up, shows up at my now-front door. Thirty-five senior high school girls and two nuns and the driver disembark. I by then had enlisted all my neighbors, and they all knew what was happening. I'm new in the neighborhood, so I'm hardly here myself. A couple of simulator guys, Pleddie [M.] Baker and his wife were just up the street, and that's why I got in that neighborhood. These girls came in with all their stuff they traveled with, and for the next three days, they camped out in my house. The two nuns slept in my bed; I split them all over the living room and dining room, and I actually had a couch, so somebody might have got a couch, but I never saw that, and then I slept in my library, just on my own sleeping bag, on the floor. I was a father-confessor for this whole thing; everything that was broke, the cameras that didn't work, the this and that, whatever had to fix suddenly, or I would delegate to some of my neighbors about keeping the herd under control.

The girls got in Friday night. The launch was close to noon, and so we went and saw the launch, and they were just right on the main road between the VAB [Vertical Assembly Building, later renamed Vehicle Assembly Building] up past the Shuttle runway. Of course,

there was no runway then. We were out on that road, so they saw a beautiful launch, and then I had security work with them avoiding the post launch traffic.

We took them down some back roads and jumped out through the Cape [Canaveral] onto the beach, and I had arranged the Cocoa Beach Patrol to set up a party. We had hot dogs and hamburgers on the beach, with, again, a bunch of my support people and neighbors. These girls just had never seen the ocean. They're all from Iowa, so first time. They had a great time, Luckily, we found them all and got them back—some were out in the dunes by this time—and got them back in the bus, went home.

On Sunday, we went out to the simulator and they got to see the simulators, meet some astronauts, John Young and a couple of others, all that sort of thing. After we went to see the simulators, they went to see the entire place, got in the LM and CSM simulators. Then we came back and I think I arranged a spaghetti—you know, mega-spaghetti dinner—and I had every neighbor making spaghetti, and we had them all put together. That was another night making sure we knew where they were. Anyway, they were up and gone by 7:00 in the morning because they had to go back to Iowa because it was still April, they had to get back to school. That was that.

I was semi-exhausted already, no sleep or very little, got in the car and went to work that day. Flight was going great, and then I watched the TV show they did, video downlink come down, and I was sitting there, "That's it, I'm going home, I'm taking the rest of the day off." It was about 3:30, or something like that, 4:00, and I got in the car and drove home.

My next-door neighbor, he was part of this whole episode with the girls, and he says, "What's wrong with the spacecraft?"

I said, "Nothing, we just had a great TV show, man, it's really good." I don't know what I was doing with the radio in my car, but I didn't have anything about it yet.

He says, "No, something's wrong."

I said, "I'll go see."

So I walk in, and when I get to my front door, the phone's ringing inside, and I open the door, and it's Slayton, and he says, "There's a problem with the spacecraft—where are you?"

"Well, I'm home, now." Turned back and got in the car, and I didn't change clothes or anything, I just went right back. That was Monday at 500PM and I got home Friday.

It was like everybody went into action. It's amazing what people did at the time. First thing we did, when we knew where we were, the crew, by that time, was in the LM, so we brought all the LM guys in, got their simulator going. We sent people across the street from Link because we found out if you build a simulator, you have a kind of thing, it's like the specifications for the spacecraft so that this battery can hold this many amps, it has to. We went over now and found out how many amps *this* battery really holds.

During the night, they changed all the parameters and constants in the spacecraft simulator so it started looking exactly like that LM. We didn't do that normally, it was just enough to be close, you didn't have to be right on. But now, this one was going to be important, that we know exactly what both vehicles did when they tested them there across the street in the MSO Building. Through the night, those guys worked to change all those, basically we call "constants," in other words, "this battery really had 42.67 amp hours in it, as opposed to 40," that kind of stuff. That was the specifications in the contract; it had to have at least 40 amp hours. All those different parameters, every tank, oxygen tank, hydrogen tank, how much did you really launch in it? How much was in it when it went? We could put all that stuff in.

Then, we started going through the procedures about what they had to do. The first one that came up was how to make that maneuver to go around the Moon quickly and get back home and figure out some procedures that would allow the LM to hold its attitude. I was involved on that because of the guidance system, and this buddy and I, his name is Bob [Robert L.] Pearson, and a guy named Charlie [Charles W.] Floyd, those guys were just working like dogs all the time to get the LM tuned up. The guys in Houston were working on another one, and that was to work on the CO_2 absorption filter. They were working on that side. It was just an amazing thing, and Tuesday and Wednesday were really bleak. Monday night through Tuesday, you were really worried that something could happen at any time. Once they did that maneuver on Tuesday and were really coming back home faster, that was good.

We knew the crew was cold, and we looked at all kinds of ways where we might be able to turn on a heater or something like that, but just couldn't find it. There was not enough electricity margin in the batteries to do anything. You wouldn't say, "They want to be warm," and then wind up not having enough energy to get back to the Earth. There was a lot of tradeoffs, not even verbalized to the crew, we just working on them internally. By about Thursday—they didn't get home until about Friday in the morning—the mood was lightening up because we were really close and knew how much energy was still in those batteries because we were watching the data and saw what our simulator was doing. Then we'd get a report from our guys in the Control Center about what's going on, the job I had done on other flights. We could call them and they'd read out the numbers to us right then, so we knew how good it was doing, and the LM was doing really well.

It was doing good enough that we were going to breathe a little sigh of relief. I sent the secretary out, once I gave her some money, and she just went and got me some underwear and a

couple of clean shirts, and literally, we just stayed right there. We had showers because the guys, they would simulate sometimes with their space suits on, so they'd shower when they come out. I just took a shower there and went back to work. Sometimes, you'd just put your head down on a table and sleep for an hour or two, one of those things, just like I'm doing right now, with the arms crossed, and you put your head down.

It's funny that all these people, they have pictures of all these cigars out and everything like that, and every flight, the cigars were out but they didn't come out on Apollo 11 when you landed. They came out when you got them home. The cigars came at the end. So many times, you'll see books or see places where it's misrepresented, and says, "This is when they landed on the Moon." No. Not until you got them back on a carrier, that's when you got to celebrate—and this one was the special one. I didn't want a cigar; I just wanted to go home and sleep. Just knowing they were down and they were okay, as soon as you see them on the deck. We'd lost Gus [Mercury-Redstone 4], his spacecraft [*Liberty Bell 7*], so being in the water was not enough—you had to see him walk on the flight deck, then things were okay.

WRIGHT: Yes, that was a good vision, wasn't it?

HUGHES: Yes, it was really good. When they finally came and did *Apollo 13* [movie], they did a hell of a job in terms of some of those very emotional times, so that was good. Ron Howard [director] has done a good job on a lot of his stuff. He's done very well for us.

WRIGHT: Apollo 14 had to be kind of a unique flight, mostly just because you were working with Shepard.

HUGHES: I got in a lot of fights with Al. Al had flown and, of course, had all the accolades thrown at him. Al, as far as I was concerned, he'd never been in space. He had never touched the stick. He'd never done anything on board it was preprogrammed. When he got in the simulator—and I knew that before 12, that guys were always saying it—he would run out of fuel, the maneuvering fuel. He was very ham-fisted on the stick. He would steer the thing so hard, like when he'd make a maneuver, he would get up such rotational speed and then he would have to take all that out and slow the speed down and stop when he got there. You should follow the procedure on spacecraft: give it a little bit of velocity and wait for it to come around to where you want to be, and then stop. That's the John Young school of saving fuel.

We'd have to tank it up again—we actually had to put more fuel in the tanks and let him follow-on on a rendezvous, or something like that, and I remember talking to Glynn [S.] Lunney about this kind of thing, saying, "What the hell are we going to do," because I think he was prime Flight Director. He was at least the one I talked about it; I can't remember. I asked the guys all across the board, and everybody agreed. There was several RCS modes—kinds of maneuvers in the CSM or LM. There was a direct mode where you put the stick over and it would fire until you let go, it just did that. But, then you had another one called pulse, it was the pulse mode where you put the stick over, it would fire for 0.05 seconds, just a little blip, and that was really good for fine maneuver because you could blip-blip and you'd watch and see what it's doing, and then one more, or take it out and stop the maneuver. So, you could do fine maneuvers, especially if you're going to dock.

I got everyone to follow this rule: "We will fail direct mode every time he gets in the simulator, and he can only do pulse."

Al came down and says, "You can't fail all six axes," plus or minus.

I said, "To hell with it, bad manufacturer or something, it's a terrible thing, isn't it? Live with it." He went to talk to my boss and he went to talk to Slayton, he went and talked to everybody. I'd been there already, I said, "We've got to teach him how to fly." He did learn. I mean, he slowed down, so finally, after a month, because he couldn't get anything out of it but a pulse each time, and so then he learned a little bit of just waiting, start the maneuver, wait for it to come around to the right place and stop it. Later, obviously, we gave him back direct mode, but then he'd switched to pulse. He would make the decisions on his own. We got through all that fairly smoothly.

WRIGHT: That's a good instructor, to find a way to teach a student.

HUGHES: That's it. Some of the astronauts were just big about themselves; they just were who they would have been before they were selected. Other people got in trouble, and they would begin to, say, maybe get full of themselves, let's say it that way. "Oh, I'm an astronaut, I know all this."

I said, "Here, you're not showing me anything so far."

WRIGHT: We're going to be asking you if they're ready to go, right?

HUGHES: Yes. It was just that important thing, and it was also teaching the instructors. I said, "Your job is to keep them alive; make sure their wife is not a widow, okay?" In that case, we'd say it that way because that was all there was, only men. But you've got to keep them alive,

which means if they're screwing up, you got to call it on it. That's why when we got into Shuttle, later, I instituted a thing where the same crew had the same instructors all the time. That way, they got way past that, "Oh, this is John Young, and I'm [only] a GS-9 and I can't tell him what to do."

I said, "You're going to have a beer with him after work and you're going to do all kinds of stuff, and when he screws up, you've seen him, so you'll be able to talk to it." It worked out well. I would still fly that way, some instructors are prime on each crew, would have a set of dedicated instructors.

WRIGHT: It's interesting to listen how you created your own playbook in order to instruct your instructors on how to coach.

HUGHES: Yes, it was important to do that. It's kind of what happened—I didn't like the way we trained Apollo, so after Skylab, when I got thrown out of flight control, that's a whole other story.

WRIGHT: We'll get to that.

HUGHES: Yes, come back to that the next time. I would set out to create a very professional team of people who would be able to do, whether I was there or not, they were going to get it done.

WRIGHT: How did the Lunar Rover make any difference on how you trained your astronauts?

HUGHES: The Rover didn't hit the door until [Apollo] 15, 16, 17. We knew it was coming, and the people who built it, it was GE at the time, they gave us a Rover that would be used down there at the Cape. Some good friends of mine, Bob Kain is one who simulated and instructed on that thing. They drove it around the swamps at KSC. I drove a bit everything, but I didn't work directly on it. I'll tell you a story on 16, it was funny, this happened for real. They were about a couple weeks from flight, and the way it worked now, you'd get in the simulator and fly into the orbit of the Moon, and then they'd get into orbit. Then you'd simulate getting into the LM, and two guys would get there, and then they'd go through the landing, where this guy watches them and talks back through the procedures, good, either the same day or different days, of course. Then, they would get out and walk over and get in this mock-up and come down the stairs like they were going through all that stepping on the Moon process. And we're doing this with Houston, so you'd see this whole timeline going on.

They would go on the side of the LM where the Rover was, they would lower the Rover. Have you ever seen it come down? They've got videos around. I'll talk more about that at a different time. They'd get the Rover down, and then they would just leave that because we'd pack it and put it back in, and they'd go outside, and then we have the electric training Rover sitting outside the door. We're in Florida; this is where the new building is where they put all the Space Station parts together. There's a little building behind it, all this stuff was in M7-409, believe it or not, I can even tell you that number. That was just built; it was a fresh-built building, just for Apollo training. That's where the three simulators were.

They'd go out the back door, and then they would drive around the Rover, and we had different places set up where they had rocks, sand there, and so they'd drive a certain distance

and then they'd stop and they'd get off and they'd mess with some rocks and collect a few samples, and go to another place. John Young and Charlie [Charles M.] Duke were doing this scenario, going out there, and so it's broiling hot sun and everything, and people follow along where they're stationed out there to watch them do it and take pictures and do whatever they need to support them.

I was inside doing something, and all of a sudden, I hear them, on the air-to-ground; you could hear the simulation going on through the building. Charlie says, "Houston, this is Apollo 16," or they were calling it "Rover," and he says, "Could you have the Florida Parks and Wildlife people come out here?" The guys told me later, and they took pictures, that there was this huge, it had to be a 16-foot alligator stretched across this dirt road out there. It was just sunning. Here comes the best the human race can do, coming up on this thing with their suits on and they're steaming, they have a cooling system going on, and here's this prehistoric thing draped across the road, literally from side to side. Here comes some dude in a pickup truck and comes up behind them, stops and gets out with the noose, and he didn't want to do much to him so he just threw the thing around his nose and started pulling him that way. It was pissed off, but it flopped into the water beside and he undid the [noose], and gets back in the truck and drives away. The simulation goes on, they go down the road. It's just part of life down there.

WRIGHT: It prepared them for whatever they found on the Moon, right?

HUGHES: Exactly, exactly. "No, no," it's like, "Okay, just another gator."

WRIGHT: Just another day?

HUGHES: We used to have a sign in that building—because the way the floor is raised 3 feet above the cement and there's all the cables running, when you had to feel a cable sometimes, follow it—it says, "If the cable moves, let go." They would get in sometimes, and all of a sudden, a big, python-looking bullsnake, or sometimes even a rattlesnake, but they'll let you know if you're in close, but it was generally not a dangerous one, but you don't want to find out.

WRIGHT: No, I don't even want to think about the pranks that might have been played with snakes and gators.

HUGHES: Yes, exactly.

WRIGHT: Horrible, horrible. We're right around the time—you want to stop, or you want to go on and finish and talk about the rest of Apollo?

HUGHES: Let's go through the rest of them because about at 13, I had bought my house, remember, that was two weeks before, or three weeks before. Went through all the visit with the girls, and then, we stopped until 14. When I left, I really had to unwind after that one, so I took a long trip to Halifax, Nova Scotia, and I wanted to go see the Bay of Fundy. I took off and I was gone for three weeks. When I came back, I was ready and set to go to work, and 14, 15, 16, 17. I got a call from Houston, again, they say, "Would you like to move to Houston?"

I said, "No, I just bought a house here."

They said, "All right."

I came back after my vacation and they were back on the phone, and they said, "Would you like to move to Houston?"

I said, "No, no, I don't."

They said, "How about TDY [temporary duty]?" I couldn't say no to that. The training was going really well. [Apollo] 14 had its own problems, I had that going on, but we have Al under control. Ed [Edgar D.] Mitchell, we never got under control. Have you done one with him?

WRIGHT: I didn't talk to him, but yes, we have done one with him, yes.

HUGHES: Ed was interesting. We had more fun with him because he was speaking to the people that we couldn't see in the room, all kind of things like that, but we had a lot of fun with that among ourselves, the things we'd talk about Ed.

The training was working really well, they would slow down because they're fixing all the things they did with the plumbing in the Service Module, just make sure that couldn't happen again after 13. From then on, even if you got the explosion or a major leak, you wouldn't lose all your oxygen because you had check valves to make sure it wouldn't run out of the other tank, through the hole you made, and some other stuff. Do you know how the explosion occurred? Maybe we stop on that, let's finish up 13.

The story I got—and this, of course, I knew a lot of people down there—Beechcraft built the oxygen tanks, and along the way, they dropped one. Physically dropped it, and when they did that, it looked pretty good, but they had bent the neck of the outlet—and these tanks, there's only one-in, one-out, you just fill in the same place you take it out—and then there were heaters

inside, and there were fans to stir it up. They went through it and sent it to Tulsa, where they built that tank into the Service Module for 13. They sent it to Florida, and there it was. Now there was a whole separate thing. Along the way, back in, I think it was 12, they had a tank that might have been similarly damaged, but at least they go through a Countdown Demonstration Test, that's a CDDT.

They would load it all up, all the fuel and the whole thing, everything, but they have actually special shorting plugs that would make sure that the engines would not fire. They would actually fix it so you couldn't launch, you couldn't find anything, it's all these safety plugs that they put in. When they got through, then they'd drain out all the fuel and clean it up. The oxygen tank didn't drain out very fast on this test. And this is after you've been sitting there for 16 hours, or something like that. They said to drive the oxygen out of that tank, they'd turn on these heaters and they'd just add a little bit of heat and then raise the pressure in the tank and make all the oxygen get out so we can go home.

It took a long time even when they did that, so there was a mod to change the voltage on this heater. In other words, instead of a 20-watt heater, it was a 30-watt heater or 40-watt heater, so that they just were going to put more energy into that heater to make this thing, if anything happens. That's two totally separate things. Now, all the stuff came together and they did this test on Apollo 13, and of course, because the neck was crimped, they went through their Terminal Countdown Demonstration Test, and it was slow to get the oxygen out.

They turned on the heater, but the thing is, the Cape had made the modification to put the higher voltage on that heater, but this was not a vehicle that had that mod yet, the next service module was modified with the bigger heater that could take the higher wattage. So they cooked this heater, they put too much on it, it got over-hot. What people didn't know is that the wires in

this oxygen, they had to have Teflon insulated wires because if you put any kind of organic material in oxygen, it becomes an explosive itself. Now, if you overheat Teflon—you obviously don't overheat your frying pan—it turns back into some organic material, some goo.

That good insulation was on those wires now turned back, they're no longer Teflon, they're whatever the hell they are when you've overheated. Then, that's it, nothing happened. Now, where it was a good insulator before, now it's just organic materials, so it's not a good insulator. Now, you launch. They go out on the lunar trajectory. The pressure's adequate enough pressure in the tanks for a day and a half. Then, you get out there, 36 hours or whatever it is, and the pressures get down a little bit, and somebody says, "Let's stir up the cryo." In this case, there's two things happen. The heaters would get hot, but they'd just have spherical levels of heat, but you had a fan that would circulate the heat away, so you'd spread it around.

Swigert just threw the switch to stir the cryos, which meant the heaters and the fans came on, but now the organic material is now in oxygen again, so now it's ready to explode. It's not a good insulator anymore, so you got a short, so you got pure oxygen, you got a fuel, and you got a spark, and that's what took out the whole side of the vehicle. Everybody's just shocked by this; it's almost like somebody put a bomb in the tanks like that. That was a whole set of people saying, "How could this happen?" Then, when they traced back all these steps, they could see where we had done that. The big thing was the tank being dropped would have been okay if the other thing happened, the thing of the voltage change, they went out of sequence down at the Cape, so if they put in the lower voltage, it would have been okay. That would have crisped the Teflon wires, see what I mean? There's no one thing happened, one way. Most disasters are like this, a series of little things.

That happened, that caused a lot of ramifications of changing the hardware going through, so that was that summer. We'll just stop. They called me, so I started going to Houston, we can pick it up there. That's the middle of '70, and my life is changing drastically.

[End of Interview]